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- USSR -

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THERMAL BOUNDARIES OF THE INITIAL CRYSTALLIZATION OF CLOUDS
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Following is a translation of an article by A. P. Chuvayev in the Russian-language periodical *Meteorologiya i gidrologiya* (Meteorology and Hydrology), Moscow, No. 3, March 1960, pages 26-28.

The establishment of the temperature of the initial crystallization of supercooled peaks of convective clouds is very important both in investigating the mechanism of the formation (conditions of origin) of naturally developed precipitations, and especially in investigating the conditions conducive to the artificial formation of precipitations by clouds of a convective nature.

In article (3) the author presented the characteristics of the temperature at the level of the upper boundary of Cu cong clouds, derived from the materials of observation on the development of convective clouds in 57 zones of the southern regions, and in 41 zones of the northwestern regions of the European part of the USSR. These observations were mainly carried out during the periods of the maximum development of convection, when the most developed Cu cong clouds in the majority of cases were no longer increasing along the vertical, and when, together with Cu cong cupolas, Cb with "anvils" were already developed. Work (1) analyzes the characteristics of the most developed clouds, i.e., Cu cong, having the greatest vertical magnitude, and consequently, in the majority of cases, also the lowest temperature at their upper boundary, of all the clouds not covered with ice in the field studied.

In 1957-58 the author carried out scientific-research flights in the region of Lake Sevan (Armenian SSR). As had been done earlier, observations of clouds were successfully carried out during the period of the maximum development of convection during the daily variation, when the main field of clouds and the most developed Cu cong had already stopped increasing along the vertical.

However, in contrast to the preceding cases, when many flights were "through flights," in carrying out research in the Sevan syncline, we very often succeeded over a protracted time period in carrying out observations on the development of some cloud sections; therefore, it was often possible to discover immediately the appearance of a fibrous structure at the peaks of Cu cong clouds.

Inasmuch as at the present time there still do not exist means of determining by instrument the presence and concentration in the cloud of particles of the solid phase of water, it is acceptable to assume for the time being that the appearance of the fibrous structure at the peak of the cloud is the only conclusive evidence of the initial process of its crystallization.

Having obtained from the data of the vertical sounding of the atmosphere the temperature values at the level of the appearance of a fibrous structure in the clouds, we can get an idea of the temperature characteristics of the initial process of the crystallization of clouds.

The flights over the basin of Lake Sevan were timed for periods of the primary maximum (May-June) and secondary (September-October) maximum of precipitation. Observations were made over a period of 73 days on which there occurred convective cloudiness (of which 48 days were in May-June and 25 days in September-October). However, the level and, consequently, also the temperature of the initial crystallization of Cu cong clouds were established in only 59 cases (of which 36 cases occurred in May-June and 23 in September-October). The results obtained are cited in Table 1.

Table 1

TEMPERATURE AT THE LEVEL OF THE INITIAL CRYSTALLIZATION OF CLOUDS
IN THE BASIN OF LAKE SEVAN

Temperature Range	Number of Cases	Percent
-12, -14	4	7
-15, -17	6	10
-18, -20	9	15
-21, -23	19	32
-24, -26	12	20
-27, -29	6	10
-30, -32	2	4
-33, -35	1	2

The data of this table indicates that in the region of Lake Sevan more than half of all the cases (52%) of the recorded initial crystallization of Cu cong clouds fall within the temperature range -21 to -26° C. Apparently, it can be maintained that with a further decrease in temperature there occurs a decrease in this frequency. However, it is absolutely not limited by the temperature limit -35° C.

In analyzing the data of Table 1 it is necessary to bear in mind that the results cited in it bear the "imprint" of the limited altitude of our flights, because the majority of them were carried out in LI-2 and IL-12 planes and the flight ceiling rarely exceeded 7,000 meters above sea level. Naturally in all those cases where the upper boundary of Cu cong clouds exceeded 8,000 meters, the absolute fixing of the time and altitude of crystallization was as a rule practically impossible. Consequently, on the whole, such cases were not included in Table 1. Let us note that almost all the data included in Table 1 on initial crystallization in the temperature field below -30°C were obtained (recorded) during flights on the TU-104 plane.

In addition, in the mountainous regions of Armenia, as a rule, it is not possible to carry out flights on LI-2 and IL-12 planes in the presence of an intense development of cloudburst and thunderstorm activity. Consequently the zones of the rapid setting free of large reserves of energy of instability also were not included in the observations and the data of Table 1.

If one agrees with the statement made in work (3), viz., that the temperature frequency of the upper boundary of the most developed Cu cong observed in the field of Cb rain clouds can simultaneously indicate the probability of the conversion of dense cumulus clouds into cumulus-nimbus clouds, thus characterizing the conditions of the initial crystallization of clouds and the occurrence of precipitation in these regions, then a comparison of the data obtained for the northwestern and southern regions of the European part of the USSR with the data of Table 1 is of much interest. Such a comparison is all the more substantiated in that the results analyzed in work (3) also do not include cases of the rapid liberation of reserves of energy of instability.

This comparison is made in Figure 1, in which are reproduced the data of Table 1 and the data of the temperature frequency at the level of the upper boundary of Cu cong clouds in the northwestern and southern regions of the European part of the USSR.

From our point of view Figure 1 is very significant. It indicates that in connection with the beginning of the process of the crystallization of supercooled peaks of Cu cong there occurs a decrease in temperature frequency at the level of their upper boundary, already starting from the values below $-8, -10^{\circ}\text{C}$ in the northwest, and below the range $-11, -13^{\circ}\text{C}$ in the south, of the European part of the USSR. Thus in the temperature range of about -23°C , the frequency of these values constitutes about 1% in the south, and falls to zero in the northwest, of the European part of the USSR.

In the basin of Lake Sevan, as has already been indicated, in general no crystallization of Cu cong clouds was noted at temperatures

above -12°C ; and the greatest frequency of cases of the initial crystallization of Cu cong clouds and, consequently, also the greatest frequency of temperatures at the level of their upper limit, falls in the range -21 to -26°C .

It should be kept in mind, moreover, that not always do the processes of crystallization begin at the densest peaks of Cu cong in the observed field of clouds. Often it happens (especially in the basin of Lake Sevan) that the denser peaks of Cu cong remain uncrystallized for a long time, whereas the lower peaks of Cu cong (with higher temperature at their upper boundary) acquire a clearly expressed fibrous structure.

The entire group of the above-cited materials indicates the unusually sharp differences of the thermal boundaries of the initial crystallization of dense cumulus clouds in individual physicogeographic regions.

Of course, in the presence of the individual types of meteorological processes in each of the regions, significant deviations from these "norms" are possible. Apparently, in the presence of these special processes, even in the more northern regions of the European part of the USSR, often to be found together with Cb anvils are Cu cong cupolas not covered with ice and having a large vertical thickness and very low temperatures at the level of their upper boundary. As has already been indicated (4), the author, participating during the period 22-25 August 1956 in the flight of the TU-104 plane on the Moscow-Irkutsk route, observed that not only cumulus-nimbus clouds but also many thick cumulus clouds often reached the altitude of the tropopause. On the night of 16 to 17 August 1954, N. F. Kotov studied by means of radar at the small village of Voeykovo (near Leningrad) an intensive development of thunderstorms whose "radar zone" reached the lower boundary of the stratosphere, located at an altitude of about 12 km. N. A. Titov (2), in testing jet aircraft on the Moscow-Omsk route in the summer of 1955, repeatedly noted that the upper boundary of cumulus-nimbus clouds and thick cumulus clouds reached altitudes of more than 10-12 km.

Analogous information may be obtained also for other physicogeographic regions from a number of literature sources. Thus, for example, according to the data of Workman and Reynolds (8), in the investigation of 12 thunderstorms in New Mexico it appeared that the first reflected signals obtained from the cumulus clouds which developed were concentrated approximately in the range -10° . However, Braham, Reynolds, and Harrell (5) indicate that, according to observations with a 3-cm radiolocator, carried out from 14 July through 15 August 1950 in Socorro (New Mexico) at temperatures above -12°C , not a single convective cloud giving a

radar echo was discovered. At temperatures between -12 and -24°C only about 20% of the clouds gave a reflection on the locator.

An interesting example may be found also in one of the works of Langmuir (6), in which he cites the following unusual physical characteristics of one of the clouds studied, obtained also in New Mexico on 21 July 1949. The peak of this cloud by 9:57 reached an altitude of 26,000 feet (7.9 km), where the temperature was -23°C . Afterwards the vertical velocity of the development of the cloud unexpectedly increased and its peak rose upward with a velocity of 1,200 feet per minute (6 m/sec), until at 10:12 it reached an altitude of 44,000 feet (13.4 km) at a temperature of -65°C . But at 10:06, when the peak of the cloud was at an altitude of 36,000 feet (11 km) at a temperature of -49°C , the radiolocator screen picked up from the cloud the first reflected signals from an altitude of 20,500 feet (6.2 km) at a temperature of -9°C . Six minutes after the first radio echo, "the radar zone" of the cloud extended to an altitude of 34,000 feet (10.4 km), where the temperature was -43°C .

If in the given examples the materials cited did not bear the imprint of the specifications used in these observations of various material-technical methods (of various power, of the permissible capacity of radiolocators, etc.), then apparently both these cases, as well as cases of the above-cited observations in individual regions of the territory of the USSR, must find their explanation in the characteristics of meteorological processes.

It should be indicated that the question of the causes of differences in the magnitudes of the initial temperature of crystallization of the peaks of convective clouds in various physicogeographic regions and in the presence of various meteorological processes is one of the knotty questions of the physics of clouds and precipitation. It is still far from a definitive solution (1) and will have to remain a subject for special investigation.

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FIGURE APPENDIX

Figure 1. Recurrence of various temperatures at the level of the upper boundary of Cu cong in the northwestern (1) and northern (2) regions of the European part of the USSR and at the level of the initial crystallization of Cu cong in the basin of Lake Sevan (3).

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- END -

FIGURE APPENDIX

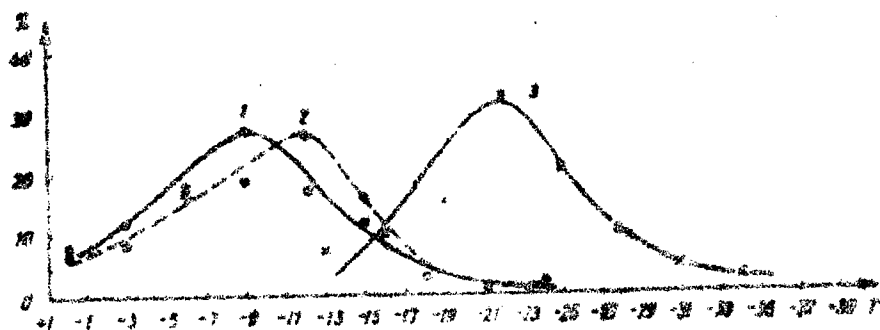


Fig. 1